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Superflares on Late-Type Stars

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Abstract. We present the results of an extensive survey of superflares on late-type stars (G, K, and M-type main sequence stars) using the *Kepler* satellite data. Wefound about 6,800 superflares on late-type stars from the data of about 120,000 stars observed over 500 days. The total bolometric energy of superflares in oursample ranges from 10^{32} erg to 10^{36} erg. Our data suggest that the occurrencefrequency of superflares depends on the surface temperature and the rotationperiod of stars. Superflares on M-type stars occur about 10-100 times morefrequently than those on G-type stars. Our results suggest that the average frequency ofsuperflares releasing 10^{34}-10^{35} erg of energy (100-1,000 times larger than the largestsolar flares) on M-type stars and Sun-like stars is once in 10 years and once in a few thousand years respectively.

Keywords. stars: flare, stars: late-type

1. Introduction

Solar flares are caused by the sudden release of magnetic energy stored near sunspots (they release 10^{29}-10^{32} ergs of energy; Shibata and Magara 2011). Similar flares are observed on many stars and larger "superflares" are seen on a variety of stars including solar-type stars (Schaefer *et al.* 2000, Balona 2012 and Maehara *et al.* 2012). Since the habitable zone around M dwarfs is closer to the host star (0.1 AU) than our solar system, high-energy charged particles and UV radiation from superflares may affect the retention and the chemical composition of planetary atmosphere (e.g. Segura *et al.* 2010). In this paper, we present the occurrence frequency of superflares with $\sim 10^{35}$ ergs of energy and correlations between the frequency of superflares and properties of host stars.

2. Data

We searched for flare-like events (sudden brightenings) by using the *Kepler* data. We analyzed the long-time cadence, PDC light curves observed between 2009 April and 2010 September (Q0-Q6 data). We used the effective temperature ($T_{\rm eff}$) and the surface gravity ($\log g$) available in the *Kepler* Input Catalog (Brown *et al.* 2011) to select M, K, and G-type main-sequence stars. The selection criteria and the total number of samples are summarized in table 1.

3. Results and Discussion

We found ∼6,800 flares on M, K, and G dwarfs from the *Kepler* data. As shown in Fig. 1, typical amplitude of detected flares on late-type stars ranges from 0.1 to 100%. The duration of superflares are typically about 0.1 days (due to the time-resolution of ∼30 min, flares with short duration were not detected). The total bolometric energy of flares

Table 1. Selection criteria, total number of stars, detected flares and flare stars

	$T_{\rm eff}$	log g	$\mathbf{N}_{\rm stars}$	$\mathbf{N}_{\rm flares}$	$\mathbf{N}_{\rm flarestars}$
M-dwarfs	<3900	$\geqslant$ 4.0	~1970	1928	117
K-dwarfs	3900 - 5100	$\geqslant$ 4.0	~26600	3335	399
G-dwarfs	5100 - 6000	$\geqslant$ 4.0	~94600	1547	279

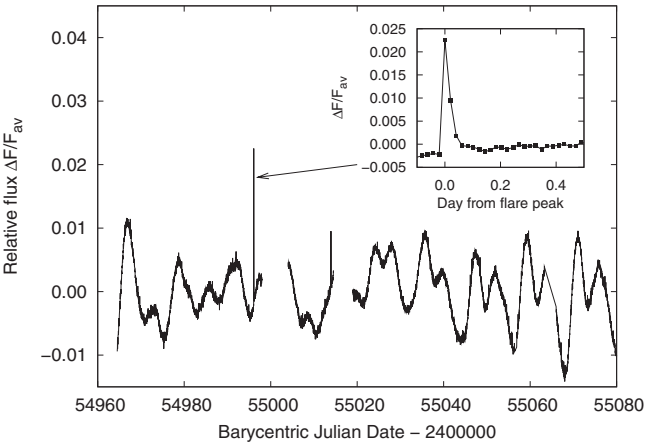

Figure 1. Light curve of a typical superflare on KIC 10524994

in our samples ranges from 10^{32}-10^{36} ergs. The number of detected flares, the number of flare stars, and the fraction of flare stars among M, K, and G-type stars are summarized in table 2. The fraction of flare stars among M dwarfs (~6.0%) are higher than that of flare stars among G dwarfs (~0.3%).

Fig. 2a represents the frequency distribution of superflares as a function of the total energy of superflares. The occurrence frequency distribution of superflares in the large-energy regime ($\geqslant\sim 10^{34}$ ergs) can be fitted by a simple power-law function. The power-law indexes of frequency distributions are -1.6 ± 0.2, -1.7 ± 0.2, and -2.2 ± 0.2 for superflares on M, K, and G-type stars. The frequency distribution function of superflares on late-type stars is similar to those of solar flares (Closby *et al.* 1993) and stellar flares on red dwarfs (Shakhovskaia 1989). Superflares occur more frequently on lower-temperature stars. The frequencies of superflares of 10^{35} ergs on M- and K-type stars are about 20 and 6 times higher than that of superflares on G-type stars. The average occurrence frequency of superflares with 10^{35} ergs of energy on M-type stars is about once in 10 years, and that of superflares on sun-like stars (G-type main-sequence stars with $P_{\rm rot} \geqslant 10$ d) is about once in 5,000 years.

The fraction of flare stars among M-type stars is higher than that among G-type stars. As shown in Fig. 2b, the fraction of flare stars which show superflares of energy $\geqslant 5\times10^{34}$ erg depends on the surface temperature of stars. For stars without short-period variations, the fraction of 'superflare stars' among early M-type stars ($T_{\rm eff}$ = 3500-4000K) is a few-10% and that among early G-type stars ($T_{\rm eff}$ =5600-6000K) is less than 0.1%. the fraction of flare stars among early M-type stars are consistent with the previous studies using the SDSS sample (e.g. West *et al.* 2008).

Most of flare stars show quasi-periodic brightness variations with periods of 1 to a few tens of days (see Fig. 1). These variations are thought to be caused by the stellar rotation or by the orbital motion of the binary system. Superflares occur more frequently

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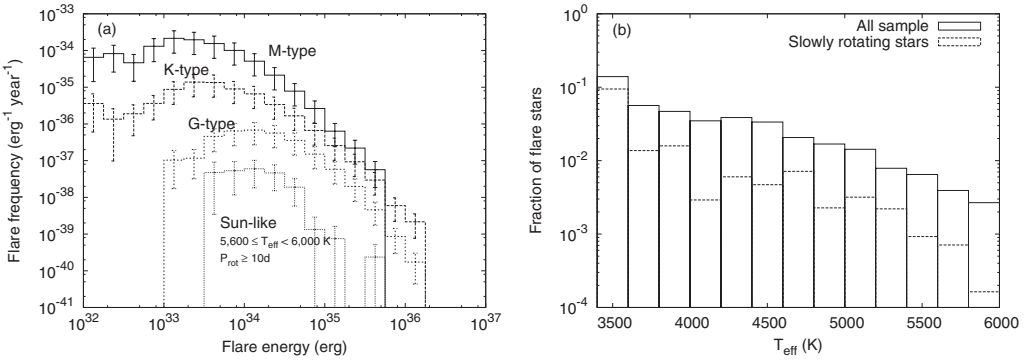

Figure 2. (a) Frequency distribution of superflares as a function of the energy of superflares. (b) The fraction of flare stars showing superflares with energy $\geqslant 5 \times 10^{34}$ erg as a function of the surface temperature of stars.

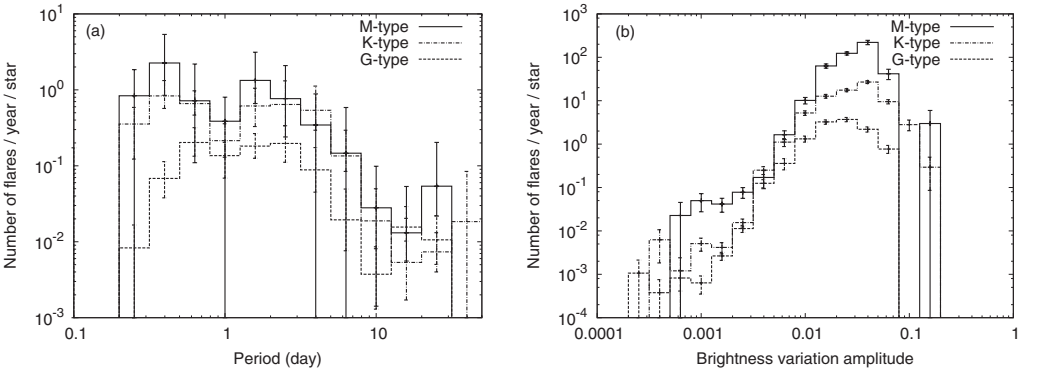

Figure 3. (a) Distribution of the occurrence frequency of superflares as a function of the period of the brightness variation. (b) Distribution of the occurrence frequency as a function of the amplitude of the brightness variation.

on the stars showing short-period variations (Fig. 3a), and on the stars showing large-amplitude variations (Fig. 3b). If we assume that quasi-periodic variations are caused by the rotation of star with starspots, the fraction of spot area and the rotation period can be estimated from the amplitude and period of brightness variations respectively. These results suggest that the frequency of superflares is related to the rotation period and the existence of large starspots is one of necessary conditions to produce superflares.

References

Balona, L. A. 2012 *Mon. Not. R. Astron. Soc.*, 423, 3420
Brown, T. M., Latham, D. W., Everett, M. E., & Esquerdo, G. A. 2011, *Astron. J.*, 142, 112
Closby, N. B., Aschwanden, M. J., & Dennis, B. R. 1993, *Solar Physics*, 143, 275
Maehara12]Maehara, H., Shibayama, T., Notsu, S., *et al.* 2012, *Nature*, 485, 478
Schaefer, B. E., King, J. R., & Deliyannis, C. P. 2000, *Astrophys. J.*, 529, 1026
Segura, A., Walkowicz, L. M., Meadows, V., Kasting, J., & Hawley, S. 2010, *Astrobiology*, 10, 751
Shakhovskaia, N. I. 1998, *Solar Physics*, 121, 375
Shibata, K. & Magata, T. 2011, *Living Reviews in Solar Physics*, 8, 6
West, A. A., Hawley, S. L., Bochanski, J. J., *et al.* 2008 *Astron. J.*, 135, 785

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